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REPORT OF THE AD HOC WORKING GROUP ON
MACKEREL EGG SURVEYS

Fisheries Laboratory, Lowestoft, 14-17 February 1984

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1. INTRODUCTION

1.1 Terms of reference

At the 71st Statutory Meeting in Gothenburg, it was decided (C. Res. 1983/2:5) that an ad hoc Working Group on Mackerel Egg Surveys (Convenor: Dr S. J. Lockwood) should be set up, with the following terms of reference:

(i) to review the available data on mackerel fecundity for the North Sea and western area, and to recommend values to be used in spawning stock estimates and their confidence limits,

(ii) to evaluate the different methods used to analyse the results of mackerel egg surveys.
It was decided, that;

(iii) taking (i) and (ii) above into account, to provide estimates of the size of the North Sea and western area spawning stocks, using the results of surveys carried out in 1982 and 1983, respectively, and comment on the confidence limits of the estimates,

(iv) to advise on the need for future surveys and their frequency, and to recommend the most suitable gear, sampling grid and laboratory sampling techniques needed to maximise the reliability of the results,

(v) to investigate, from material already collected, the possibility of estimating the spawning stock size of horse mackerel.

1.2 Participation

The Group met at the Fisheries Laboratory, Lowestoft 14-17 February with the following participants:

J. Aiken	UK (England and Wales)
S. Coombs	UK (England and Wales)
W. Dawson	UK (England and Wales)
M. Doyle	Ireland
D. Eaton	UK (England and Wales)
A. Eltink	Netherlands
J. Fives	Ireland
P. Hopkins	UK (Scotland)
S. Iversen	Norway
E. Kirkegaard	Denmark
S. Lockwood (Chairman)	UK (England and Wales)

L. Mariduena	UK*
L. Motos	Spain
J. Nichols	UK (England and Wales)
J. Pope	UK (England and Wales)
B. O'Brien	Ireland
W. Schöfer	Federal Republic of Germany
B. Thompson	UK (England and Wales)
M. Walsh	UK (Scotland)
T. Westgård	Norway

*On secondment to MAFF Fisheries Laboratory, Lowestoft from Instituto Nacional de Pesca, Ecuador

2. MACKEREL FECUNDITY

2.1 Western mackerel stock fecundity

There are four fecundity relationships which may be of some relevance to the Western mackerel stock. Details have been published by Macer (1976), Lockwood et al. (1981a), Martins and Gordo (1983) and Walsh (1983). Macer took his samples only from around the Cornish peninsula while Lockwood took samples from the main Western mackerel spawning grounds, and incorporated Macer's data. Martins and Gordo collected their fish off the Portuguese coast (sub-Area IX), an area which the Mackerel Working Group currently views as having a separate stock to the Western area (Anon. 1984). The samples analysed by Walsh were taken near Shetland and are discussed in connection with the North Sea stock (see below), but the Working Group recognised the possibility that the sample might have included some fish which had already shed some eggs west of Britain.

Thus, in the absence of any new data or evidence to the contrary the length/fecundity relationship described by Lockwood et al.(1981a) was accepted as being the most appropriate one for raising egg production estimates to spawning stock size for the western stock. The relationship is described by the equation:

$$\text{Fecundity} = 8.8\ L(\text{cms})^{3.02}$$

The standard deviations of the $\log_e$ intercept and slope are 0.4897 and 0.1370 respectively (301 counts from 99 fish). The 95% confidence intervals are ± 3% at mean length and ± 10% at extremes (25 and 50 cm).

2.2 North Sea mackerel stock fecundity

For the North Sea stock the earliest fecundity estimate of Borges et al. (1980) was rejected as being unrealistic because problems were encountered with Gilsons fluid resulting in widespread rupture of eggs. Two alternative fecundity relationships are available, these are described by the equations below and are shown in Figs 2.1 and 2.2.

Fecundity/Length

Fecundity = 1.35 x Fish length (cms)$^{3.6}$ Iversen & Adoff (1983)
Fecundity = 0.00311 x Fish length (mms)$^{3.169}$ Walsh (1983)

Fecundity/weight

Fecundity = 560 x Fish weight (gms)$^{1.14}$ Iversen & Adoff (1983)
Fecundity = 1942 + 1061.77 (weight in gms) Walsh (1983)

The relationships described by Walsh were obtained by the traditional method using Gilson's fluid while those of Iversen & Adoff were obtained by making counts on whole mount preparations and by histological studies.

The data for both investigations were collected in May 1982, the Scottish data from the Shetlands area, the Norwegian data from south west of Bergen. At the approximate mid point of the length range of both data sets (40 cms, Fig. 2.1), Iversen and Adoff's fecundity-length relationship gives fecundity estimates 44% higher than those of Walsh and well outside the confidence limits calculated by the latter (± 8% approx). No immediate explanation for this difference emerged. The Scottish data were obtained at a greater distance from the centre of spawning than those of Iversen and Adoff but had age compositions typical of the North Sea stock. The Scottish fecundity-length relationship was very similar to that obtained by Lockwood et al. (1981a) using a similar method for the Western stock, which might suggest that the source of difference lies in differences between the methods used. Clearly this needs urgent investigation. Until the source of difference can be identified it was decided to use fecundity estimates from both methods to calculate stock size for the North Sea stock.

2.3 Current studies of mackerel fecundity

A known source of error in estimating fecundity arises from the difference between 'potential' fecundity, as estimated in the fecundity investigations listed above and 'real' fecundity i.e. the actual number of eggs released. The difference being the number of atretic (resorbed) oocytes. Investigations on this subject are currently underway and Mariduena presented two working documents* on this topic. These identified two periods in the spawning cycle when atresia of oocytes takes place, one early in the maturation cycle, and one after spawning. Post spawning atresia is easier to detect and quantify than the former, and it is hoped that quantitative data will become available in the near future. Fecundity relationships might then be adjusted accordingly.

Further aspects of this work cover spawning frequency of individual fish and batch size. A preliminary account will be presented at the 1984 Statutory Meeting.

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* Copies of all working documents discussed by this Working Group are lodged with ICES.

3. THE ESTIMATION OF MACKEREL EGG PRODUCTION AND STOCK SIZE

3.1 The Western mackerel spawning stock

3.1.1 The 1983 Plankton survey

The survey was conducted in broadly the same way that it was in 1977 (Lockwood et al. 1981a) and 1980 (Lockwood et al. 1981b), except that more ships participated. During the period March to July 1983, five plankton surveys were made covering the known spawning area of the Western mackerel stock (Fig. 3.1). Six research vessels took part: ANTON DOHRN (Federal Republic of Germany), CHALLENGER (U.K.), CIROLANA (U.K.), SCOTIA (U.K.), THALASSA (France) and TRIDENS (Netherlands). Samples were taken at the centre of standard 0.5° rectangles (Fig. 3.1) using variants of the Gulf III plankton sampler with a 20 cm diameter aperture standard conical nose cone. Recommended sampling depth was to 100 m maximum, or, in the presence of a 2° to 3°C thermocline, to 20 m below this thermocline. Temperatures were recorded at the surface and maximum sampling depth at all sampling points.

Mackerel eggs were picked out of each plankton sample and the number of Stage I eggs i.e. eggs before embryo formation, was raised to the number produced per m^2 per day which was in turn raised by the area of the sampled rectangle (Lockwood et al, 1981b).

3.1.2 Estimation of 1983 total egg production by sums of rectangles

Total egg production for the spawning ground was estimated for each of the five surveys by summing the production estimates for each of rectangles sampled. Production estimates of unsampled rectangles within the main survey area were interpolated by calculating the geometric mean of adjacent sampled rectangles, following a convention agreed previously (Lockwood et al. 1981). The total production estimates for each survey are summarised in Table 3.1 and were also plotted against the appropriate mid-survey date, and a production curve drawn (Fig. 3.2). Total egg production for the main western mackerel spawning area was estimated by integration of the area under the curve.

1983 Western mackerel stock egg production: 1.50×10^{15}.

Estimates of 95% confidence intervals for the Western Mackerel egg production figure for 1983 were made by Pope and Woolner (Working Docs & C.M. 1984). They made two estimates: a low estimate of ± 24% and a high of ± 38%. Both estimates were based on the assumption of a constant coefficient of variation of the rectangle within cruise results. The low estimate was based on the coefficient of variation obtained from replicated rectangle within cruise results while the high estimate was based on overall analysis of variance (rectangle and cruise) results made on all the data. The latter estimate will therefore certainly contain rectangle x time interaction effects which will cause it to be an overestimate. It is considered that the lower figure is nearer the truth but should be regarded as an underestimate.

These values are similar to those calculated, by a different method following the 1977 survey (+30%, -20%, Lockwood et al. 1981a). As then, it must be appreciated that these confidence intervals apply only to the data set used to estimate total production. The spawning stock biomass estimate will be subject to the variance of the egg survey estimate, and also of the estimates of fecundity at length, and of the mean length estimates.

A comparison was made between the egg production estimates for 1977, 1980 and 1983. The basic spawning pattern was the same, in geographical terms, in all 3 years. It was concentrated along the edge of the continental shelf, with maximum production occurring between latitudes 49° and 50°30'N and longitudes 8°30'W and 11°W. The production curves for 1977, 1980 and 1983 are shown in Fig. 3.2. The original curve for 1980 (Lockwood et al. 1981b) showed an anomalous point for the May survey, daily production being significantly lower than the preceding and following survey estimates. Subsequent processing of the 1980 samples has shown this anomaly to occur in a wide range of fish eggs and larvae. While the cause of this anomaly is still not known, it is assumed that it resulted from a consistent (unidentified) fault in the sampling equipment. Consequently the production estimate for May 1980 has been rejected, and a new total egg production estimate made (Table 3.2).

1980 Western mackerel stock egg production: 1.84×10^{15}.

3.1.3 Estimation of egg production using the delta distribution

An attempt was made to estimate egg production and its confidence limits using the delta distribution, a distribution where non-zero values are log-normal (Pennington, 1983). The spawning season was divided into short periods of time and the survey area into strata to reduce the effects of any systematic variation with time and space respectively. The data from all cruises were pooled for the calculation of production within each of the strata and time periods. Where there were no hauls taken in any period, for any stratum, production was estimated by linear interpolation between periods for which there are data.

Using the stratification shown in Figure 3.3 and 11 x 11 day periods, a total production estimate of 2.03×10^{15} eggs was made. Production histograms for each of the strata and for all the strata combined are given in Figures 3.4 and 3.5. The estimate is considerably higher than that obtained by raising the number of eggs m^2 day^{-1} to 0.5° rectangles, summing over all rectangles and plotting against the cruise midpoints. One of the reasons for the higher production estimate may be the bias introduced by the replication of hauls in rectangles with high production. There is some evidence of this. For time period 8 (3-13 June) and stratum C the production estimate is reduced by about 10% by averaging replicate hauls rather than using them independently. In period 6 (12-22 May) there was rather sparse coverage of stratum C, with the hauls which were taken tending to be near the shelf edge where production might be expected to be high. Averaging replicate hauls in period 6 reduced the production estimate in stratum C during that period by almost 30%.

Figure 3.4 shows that the main contribution from the dominant statrum C occurred in the time periods 5 to 8 (May 1-June 13). Pennington's method of determining estimates of the mean and variance based on the Δ-distribution assumes that the distribution of the log non-zero values is normal. The distributions of the log positive numbers for each of the four time periods were normalized to zero mean and unit variance

$$\text{i.e.}\quad x'_{ij} = \frac{(x_{ij} - \bar{x}_j)}{\sigma_j}$$

where $x = \log_e \text{nos}/m^2/d$
x' = normalized numbers
$j = 5, 6, 7, 8$
$i = 1, 2, \ldots, m_j$
m_j = no. of positive values for period j

and results from the 4 strata combined (Figure 3.5). Coefficients of skewness and kurtosis were determined to test whether the composite distribution departed from normality. The values obtained were -0.736 and 2.793 (Fig. 3.6) (as against 0 and 3 for the normal), with the associated probability levels for departure from normality being $p < 0.1$ and $p < 0.7$ respectively. Further examination showed that, to a first approximation, the effect of skewness had inflated the production estimate during the four periods by about 12%.

In view of these problems it was considered that the production estimate of 2.03×10^{15} eggs was probably an overestimate. It is recommended that the method of estimating production by rectangles, described in Section 3.1.2 be adopted for estimating the 1983 spawning stock size.

In future surveys the problem of biassed sampling could probably be overcome by proper survey design (see Section 4.3), and should not prove a contra-indication to the use of Pennington's method. The probability of non-normality of the underlying statistical distribution is somewhat more fundamental, and careful consideration should be given to whether or not this would be a problem in future surveys.

3.1.4 Western mackerel spawning stock size

It is well known that the size of mackerel on the spawning grounds changes during the spawning season, the large, old fish spawn first and then the mean size and age of fish decreases (Lockwood et al. 1981a;Eltink and Gerritsen, 1982). For this reason it is advisable to estimate stock in number and biomass on a monthly basis.

Eltink (C.M. 1984) has summarised the mean length and weight data by months, of mature (hyaline eggs present) female mackerel caught by Dutch freezer trawlers in Division VIIj (equivalent to stratum C in Fig. 3.3) during the spawning season 1981-83 (Figs 3.7 and 3.8). The mean size of mature mackerel at the mid-point of each plankton cruise was interpolated from these data (Fig. 3.8) and a corresponding fecundity calculated (Table 3.1). The number of spawning fish was then calculated, assuming a sex ratio not significantly different from 50/50 (Lockwood et al. 1981b).

These population estimates were plotted against time (Fig. 3.9) and the stock in number was estimated by calculating the area under the curve.

The Western mackerel spawning stock in 1983 was:

6985 x 10^6 fish, or 2.4 million tonnes.

The same mean length, weight (Figs 3.6 and 3.7) and fecundity data were used to convert the revised 1980 egg production figures (Table 3.2) to spawning population. From these revised data it was estimated that:

The Western mackerel spawning stock in 1980 was:

7310 x 10^6 fish, or 2.9 million tonnes.

3.2 The North Sea mackerel spawning stock

3.2.1 The 1983 Plankton survey

The 1983 mackerel egg survey was cararied out by Norway in broadly the same manner as in earlier years (Iversen and Eltink, 1983). Samples were taken in 0.5° rectangles between 53°30'N and 59°N with 20 cm bongo nets towed stepwise at 5, 10, 15 and 20 m depth. The main spawning area was covered on four occasions between 24 May and 10 July.

3.2.2 Estimation of 1983 total egg production by contouring

The mackerel egg production estimate for 1982 is given in Iversen and Eltink (1983). This estimate was slightly revised in Anon. (1984), 105 x 10^{12} eggs. The estimate was calculated by integrating areas between isolines fitted by eye (Iversen 1977). A computer program may also be used to calculate egg production and such a method is described in a working document prepared for this meeting by Iversen and Westgård (CM 1984). The computer program estimated the production of 126 x 10^{12} eggs. Walsh has revised his estimate given in Walsh (1983). The revised estimate which excludes the Scottish survey results and now takes account of Iversen's (pers. comm.) egg incubation data was 127 x 10^{12} eggs and is based on the same method as applied for the Western area.

The input parameters given for the computer interpolation program were tuned by giving two individuals the same randomly picked cruise data set and allowing them to compute a production estimate independently. They arrived at practically the same figure as the computer program did after tuning. These values for the input parameters for the interpolation routine were then used for all the surveys both for 1982 and 1983. It then appeared that for several of the surveys, despite the tuning, the computer program arrived at values about 10-15% higher than by the manual method (see Table 3.3 and 3.4). The main reason for this discrepancy is that the computer interpolation routine smoothes the interpolated data more and thereby stations with high egg number will "affect a bigger area".

The production estimates for 1982 are in the range 105-127 x 10^{12} eggs and the 1983 estimates, based on the manual and computer program method, were 142 and 160 x 10^{12} respectively.

A different approach to that used in the Western area was used to compute confidence limits of egg production estimates was used in the North Sea (Iversen and Westgård, 1984). The method has the assumption that sampling has been random in time and space, which seems a reasonable assumption for the egg surveys in 1982 and 1983. The frequency distribution of the samples was then used as an "estimate" of the real distribution. This distribution was then sub-sampled repeatedly to provide a series of estimates of the sample mean. The distribution of these sample means was then examined to give 90% confidence limits for the 1982 and 1983 North Sea egg production estimates:

Year	Lower limit	Upper limit	No. of stations
1982	-18.1%	+19.0%	584
1983	-26.3%	+30.9%	369

A fuller description of the North Sea data is found on Iversen and Westgård (1984).

3.2.3 Estimation of North Sea egg production by sums of rectangles

Total egg production in 1982 was also estimated by the method of estimating production within rectangles and summing these rectangle production estimates (see Section 3.1.2). This method calculates the same egg production figure as obtained from the computer contouring program (Table 3.5).

Table 3.5 shows the egg production estimates converted to spawning stock size according to the weight fecundity relationships given by Iversen and Adoff (1983) and Walsh (1983).

3.2.4 The North Sea mackerel spawning stock size

No data were available showing the size distribution of mature mackerel during the spawning season. Spawning stock biomass was calculated directly from the total egg production estimates with the fecundity weight relationships given in Section 2.2. The results are summarised in Table 3.5. The sex ratio for the North Sea is known to be 50/50 (Iversen, 1981). The North Sea mackerel spawning stock in 1983 was 215-280 thousand tonnes.

4. FUTURE MACKEREL EGG SURVEYS

4.1 Frequency of surveys

For a number of years mackerel egg surveys in the North Sea have been undertaken annually by Norway, but also with involvement by Netherlands and Scotland in recent years. Another joint programme is planned for 1984. In the Western area comprehensive surveys have been completed on three occasions at three year intervals, 1977, 1980, 1983. At present nothing further is planned.

The principal reason for undertaking these surveys has been to provide the main stock reference point for the assessments made by the Mackerel Working Group (Anon. 1984). In the continued absence of more reliable, alternative stock size estimates there will be a clear need to continue these surveys. However, this Working Group decided that the decision on whether, and how often, these surveys need to be carried out should be taken by the Mackerel Working Group. This decision will be drawn to the attention of that Working Group when it meets 28 February 1984.

4.2 Sampling gear and station sampling strategy

Existing data on the vertical distribution of mackerel eggs indicates that occasionally they may be found deeper than the presently adopted sampling depth of 100 m. In order to reduce potential undersampling from this source, it is recommended that in the presence of a thermocline of at least 2°C over 10 m in depth, sampling should be down to 20 m below it. In the absence of such a thermocline sampling should be to the bottom or to 200 m whichever is the shallower. Under conditions of extreme and predictable stratification (~ 5°C in 10 m) such as occur in the North Sea, sampling can be restricted to the mixed layer. The speed of deployment and recovery should be adjusted in order not to greatly increase the total survey time. Further information should be obtained on the vertical distribution of eggs in the absence of a thermocline particularly during March and April.

Improved data logging facilities on some vessels have highlighted the problem of unequal volumes of water being filtered at each depth stratum during double oblique hauls. Examination of some of these data in relation to the vertical distribution of mackerel eggs has shown that errors (usually underestimates) of egg abundance of >25% may sometimes occur. This is caused by the progressively longer period that a sampler sometimes spends towards the bottom of its dive. These anomalies are not always evident in simple analogue chart records of the dive profile. There are insufficient data from all vessels to justify any attempt to correct for these errors at present. It is recommended that countries participating in future surveys should wherever possible measure the volume filtered by depth strata and attempt to improve the diving profiles by closer control. It may be possible to make some allowance for this effect but detailed information on the depth distribution of eggs would be required.

It is accepted that provided the volume of water entering the sampler is measured accurately then simple samplers such as Gulf III type or bongo samplers worked in oblique, or stepped oblique hauls, provide an adequate estimate of egg abundance. Estimates of haul to haul variance for Gulf III samplers are in the region of 20% c.v. (Harding and Nichols, Unpublished MSS). A method offering greater sampling precision than this cannot be recommended at the moment. However there are potential advantages in using modified sampling strategies of taking smaller samples integrated over longer distances. Consideration should be given to using such a strategy with its potential savings in analysis and research vessel time. The Working Group recommends that more extensive comparisons between the present method and those based on small continuous samplers, such as the Undulating Oceanographic Recorder (U.O.R.), should be undertaken as a matter of some urgency.

Savings in sampling and analysis effort may also be achieved by deriving egg production from total egg numbers as opposed to stage I eggs only. In order to justify such a procedure studies on the natural mortality rate of mackerel eggs should be undertaken. Retrospective calculation of egg production on two surveys using total egg numbers in the 1983 Western area survey gave results of 62% and 78% of the accepted value using stage I eggs.

Diel periodicity of spawning can introduce a systematic error in estimates of daily egg production, most notably when short development periods (eg ca:36 hrs for stage I mackerel eggs) are used. Ferraro (1980) suggests that this might not be a problem for consideration with mackerel, but more detailed studies on this aspect are required in the Northeast Atlantic. The use of total egg production calculations would mitigate any such problem if it were encountered.

4.3 Optimization of Future Sampling Design

Table 4.1 shows optimal allocations of sampling effort to the area x time strata (adopted for Δ-distribution analysis (Fig. 3.3)) following Neyman's method (Cochran, 1963). It is clear from this that about 70% of the sampling effort should be deployed in the time periods from 1 May to 13 June and about 40% on the Sole bank area alone. In practice logistic consideration of ships steaming times suggest that a strictly statistical optimization of the sampling effort in the various time and area strata would not be practical. The minimum effort that could be applied to the earlier periods would in practice have to be more than the optimum level. Nevertheless the design could be substantially improved with a 9-ship survey (as undertaken in 1983) if no more than single cruises covered time periods 1-2, 3-4 and 9-11 and the remaining 6 ships covered the time periods 5-8 with heavy concentration in area C. The precise area stata shown in Figure 3.3 are not necessarily optimal and could doubtless be improved by consideration of the joint results of the 1977, 1980 and 1983 surveys.

The egg surveys in the North Sea in 1982 and 1983 clearly demonstrate that the sampling scheme has not been optimal. The basic statistics for the North Sea are shown in Figure 4.1 together with the optimal distribution of sampling effort by 1x1 degree rectangles. A practical scheme of sampling effort in space is shown in Figure 4.2.

For stock assessment purposes it should be borne in mind that it is the precision of spawning stock estimates rather than the egg production estimate which is of primary interest. Precision of fecundity results is as important as the precision of egg production estimates, and could be improved at considerably less expense. With this in mind it is recommended that fecundity estimates are included as an integral part of future surveys. Sampling of the spawning population for size, age and fecundity should follow a similar strategy to that adopted for plankton sampling.

5. ASSESSMENT OF SCAD STOCKS IN ICES SUB-AREAS VII, VIII AND IX

At present the only sources of adequate data from commercial catches are from the Dutch fisheries in ICES divisions VIIe, f and j, and the Portuguese fisheries in sub-areas VIII and IX. (It is possible that scad from these areas are from separate stocks, and it might be advisable to treat them as such until more information on this subject becomes available.) Basic biological data (length distributions, mean weight at length) are available from the 1983 Dutch fisheries, and from research vessel sampling in sub-areas VII and VIII. Although progress has been made with the ageing of scad, the problem has not yet been fully resolved. The situation may be clarified when the results of a comparative study between institutes, currently in progress, become available during the course of 1984.

Provided that adequate sampling of the Dutch fishery can be maintained, it is possible that sufficient data will be available to permit an assessment of the "Celtic Sea stock" in 1985. If this were so, a reference point of stock size would be required, which could be obtained from egg survey data. Fig. 5.1 shows the disposition of individual cruises during the 3 mackerel egg surveys and the availability of data on scad eggs. As can be seen the data for 1980 is complete except for the June-July THALASSA cruise. This omission is important as available data suggests that the peak of spawning for scad in the Celtic Sea occurs during June. However, as Dutch commercial data relates mainly to 1983, it is the 1983 egg survey which should be given priority for assessment purposes, and much of the material from this survey is still to be examined for scad eggs.

As with mackerel, the estimation of fecundity in scad is a major problem. A summary of available estimates of potential fecundity is given in Table 5.1. That of Nazarov 1977 seems the most relevant, and without a major commitment of effort the use of one, or a synthesis of, these estimates is unavoidable.

If ACFM wish to continue with the attempt to assess scad stocks then a firm commitment is required from nations involved in the fishery to provide the necessary data, and also from the Mackerel Working Group to devote the time necessary to the topic in order to achieve an objective assessment. If this commitment is not forthcoming serious consideration should be given by ACFM to deleting scad assessment from its current list of objective.

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Table 3.1 Summary of the Western Mackerel Stock egg production and spawning stock size estimates in 1983

Fecundity = 8.8 length $(cm)^{(3.02)}$

	April (4^4)	May ($9-10^5$)	June ($6-7^6$)	June (18^6)	July (4^7)
Egg Production x 10^{-10}	400.4	1638.5	3135.0	1427.0	537.4
Mean length (cm) Stage 6 females	41.3	37.1	35.1	34.5	33.8
Mean Fecundity x 10^{-3}	667.808	483.050	408.611	387.879	364.595
Numbers of Stage 6 females x 10^{-6}	6.00	33.92	76.72	36.79	14.74
Total Stage 6 mature fish x 10^{-6}	11.99	67.84	153.45	73.58	29.48

Total estimate of 6985 x 10^6 mature fish

Table 3.2 Revised summary of the Western Mackerel egg production and spawning stock estimates in 1980

R.V. Cruise	ANTON DOHRN + SCOTIA 2/80	CIROLANA 4/80	SCOTIA 5/80	THALASSA	CIROLANA 7/80
Mid-date	24/3	9/4	6/6	25/6	25/7
Daily egg production x 10^{-10}	237.28	1006.09	2447.82	1967.48	24.56
Mean length Stage 6 females	40.3	39.5	35.2	34.2	33.2
Mean fecundity " "	620160	583722	412137	377782	345398
Nos Stage 6 feamles x 10^{-6}	3.83	17.24	59.39	52.08	0.71
Nos Stage 6 fish	7.65	34.47	118.79	104.16	1.42

Total Spawning stock estimate 7310 x 10^6 mature fish

Table 3.3 North Sea mackerel egg production estimates for 1982

	Stage 1 eggs	
Time	Manual method	EDB
17/5-82	0	0
24/5- 9/6-82	$2.3 \cdot 10^{12}$	$2.8 \cdot 10^{12}$
3/6-16/6-82	$2.4 \cdot 10^{12}$	$2.7 \cdot 10^{12}$
16/6-30/6-82	$2.3 \cdot 10^{12}$	$2.9 \cdot 10^{12}$
1/7-15/7-82	$1.1 \cdot 10^{12}$	$1.2 \cdot 10^{12}$
17/7-30/7-82	$0.05 \cdot 10^{12}$	$0.1 \cdot 10^{12}$
26/7-82	0	0
Total	$105 \cdot 10^{12}$	$126 \cdot 10^{12}$

Table 3.4 North Sea mackerel egg production estimates for 1983

	Stage 1 eggs	
Time	Manual method	EDB
17/5-83	0	0
25/5- 4/6-83	$0.9 \cdot 10^{12}$	$1.1 \cdot 10^{12}$
4/6-23/6-83	$4.6 \cdot 10^{12}$	$4.9 \cdot 10^{12}$
24/6- 1/7-83	$3.1 \cdot 10^{12}$*	$3.8 \cdot 10^{12}$*
2/7- 9/7-83	$1.1 \cdot 10^{12}$	$1.1 \cdot 10^{12}$
25/7-83	0	0
Total	$142.4 \cdot 10^{12}$	$160.5 \cdot 10^{12}$

* This survey covered parts of the spawning area. Therefore the estimate based on this survey was increased by 40% to give a total egg production estimate.

Table 3.5 Egg production and spawning stock size estimates for North Sea mackerel in 1982 and 1983

	1982			1983	
	Manual isolines	Computer stage 1	"Rectangle" method	Manual isolines	Computer stage 1
Egg prod • 10^{12}	105	126	127	142	160
Spawning stock size x 10^{-3} tonnes					
1.	160	190	190	215	240
2.	185	220	220	250	280

[1] Based on fecundity data given by Iversen and Adoff (1983)) See Section
[2] " " " " " " Walsh (1983)) 2.2

Table 4.1 Western area, optimal allocation of sampling effort to time (11 day) and area strata (see Figure 3.3). %.

Time strata	18/3	29/3	9/4	20/4	1/5	12/5	23/4	13/6	14/6	25/6	5/7	16/7	All times
A	–	0.005	0.1	0.05	4.1	7.7	3.7	0.64	–	0.5	1.1		17.9
B	–	0.008	0.01	0.45	0.04	–	3.4	0.29	–	0.008	0.033		4.2
C	–	1.03	0.03	4.3	12.4	9.7	12.6	6.7	2.8	2.3	1.47		53.3
D	0.008	0.008	–	0.05	0.1	–	3.0	2.5	2.1	1.3	1.9		11.0
E	2.4	0.9	–	–	0.5	0.65	1.0	0.15	1.1	0.09	0.43		7.2
F	0.002	–	–	–	0.26	0.6	0.28	0.2	1.8	3.3	–		6.4
All areas	2.4	2.0	0.1	4.9	17.4	18.7	24.0	10.5	7.7	7.5	4.8		100.0

Table 5.1 Fecundity of scad (*Trachurus trachurus* L.)

Source	Length of fish, cm	Absolute fecundity x 10^3		Relationship
		Range	Mean	
SW Africa (Komarov 1964)	22.0–38.0	12.7–740.0	178.0	–
NW Africa (Overko 1964)	22.0–34.0	3.8–151.1	34.5	–
NW Africa (Overko 1969)	27.8–35.5	39.3–226.8	129.2	–
English Channel & N. Sea (Polonsky 1969)	21.0–29.0	76.0–209.0	–	–
English Channel & N. Sea (Macer 1974)	25.0–38.0	168.0–860.0	344.7	$y = 0.0176x - 107.17$* ($r = 0.784$)
Celtic Sea (Nazarov 1977)	24.6–40.5	54.3–832.8	218.7	$y = (1.54 \times 10^{-5})x^{4.717}$ ($r = 0.68$)

* x = body length $(cm)^3$

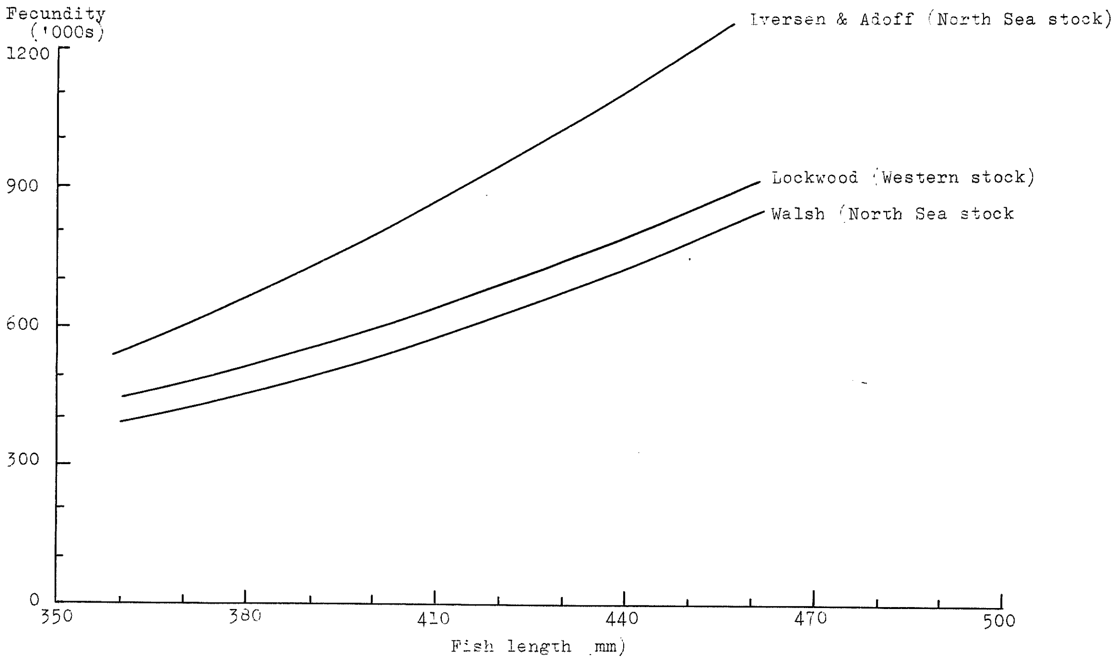


Figure 2.1 A comparison of three different mackerel fecundity/length relationships.

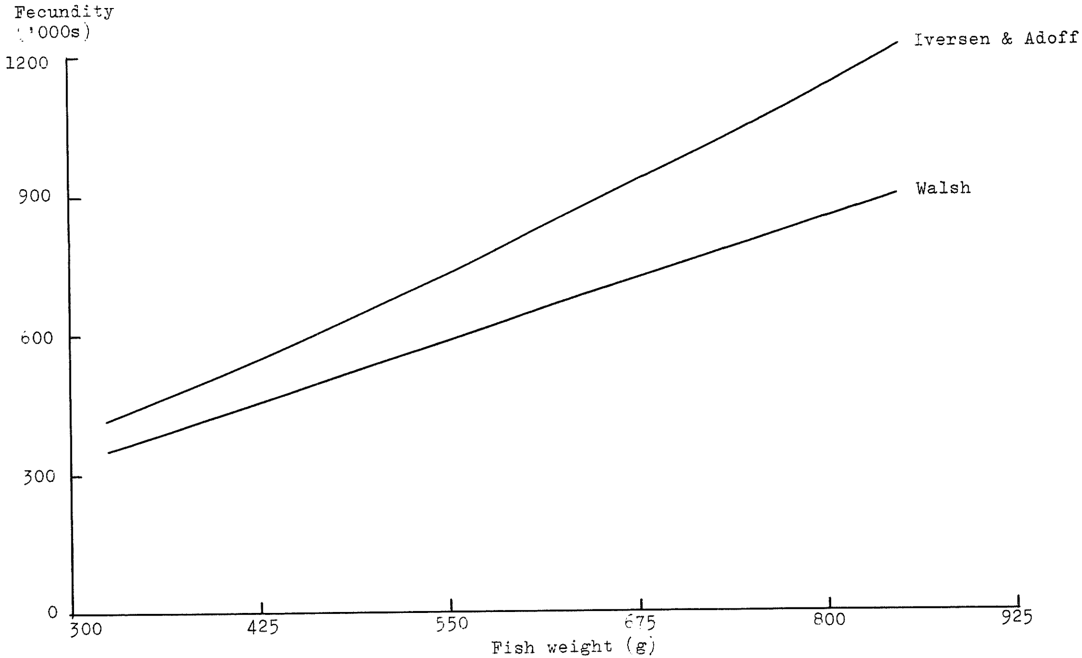
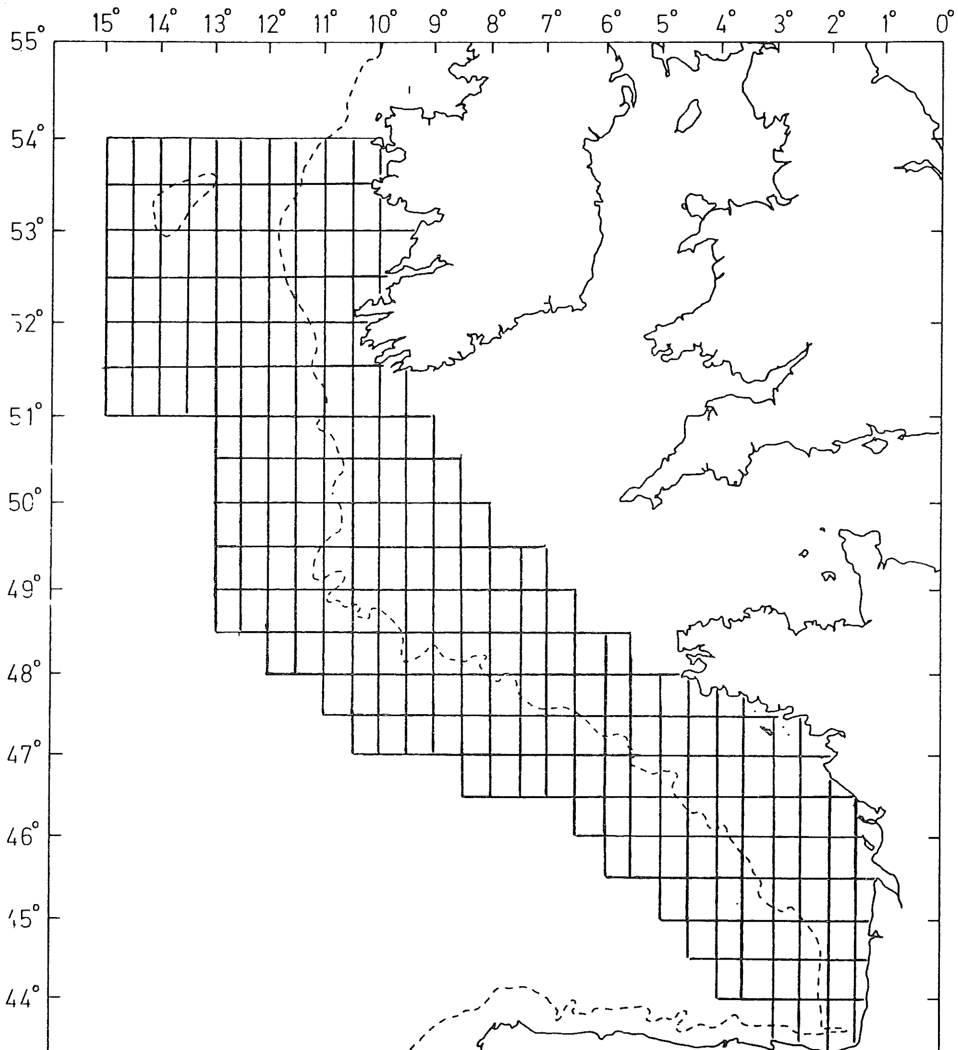
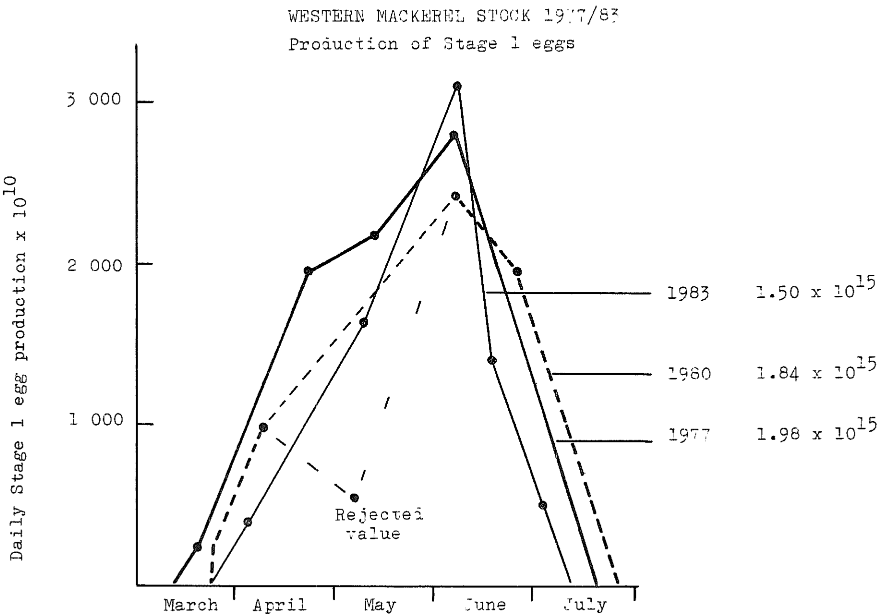


Figure 2.2 The relationship between fecundity and weight (North Sea stock).



<u>Figure 3.1</u> The grid covered in the 1983 Western mackerel egg survey.



<u>Figure 3.2</u> Western MACKEREL egg production curves 1977, 1980 and 1983. (The reasons for rejecting the May 1980 value are given in the text.)

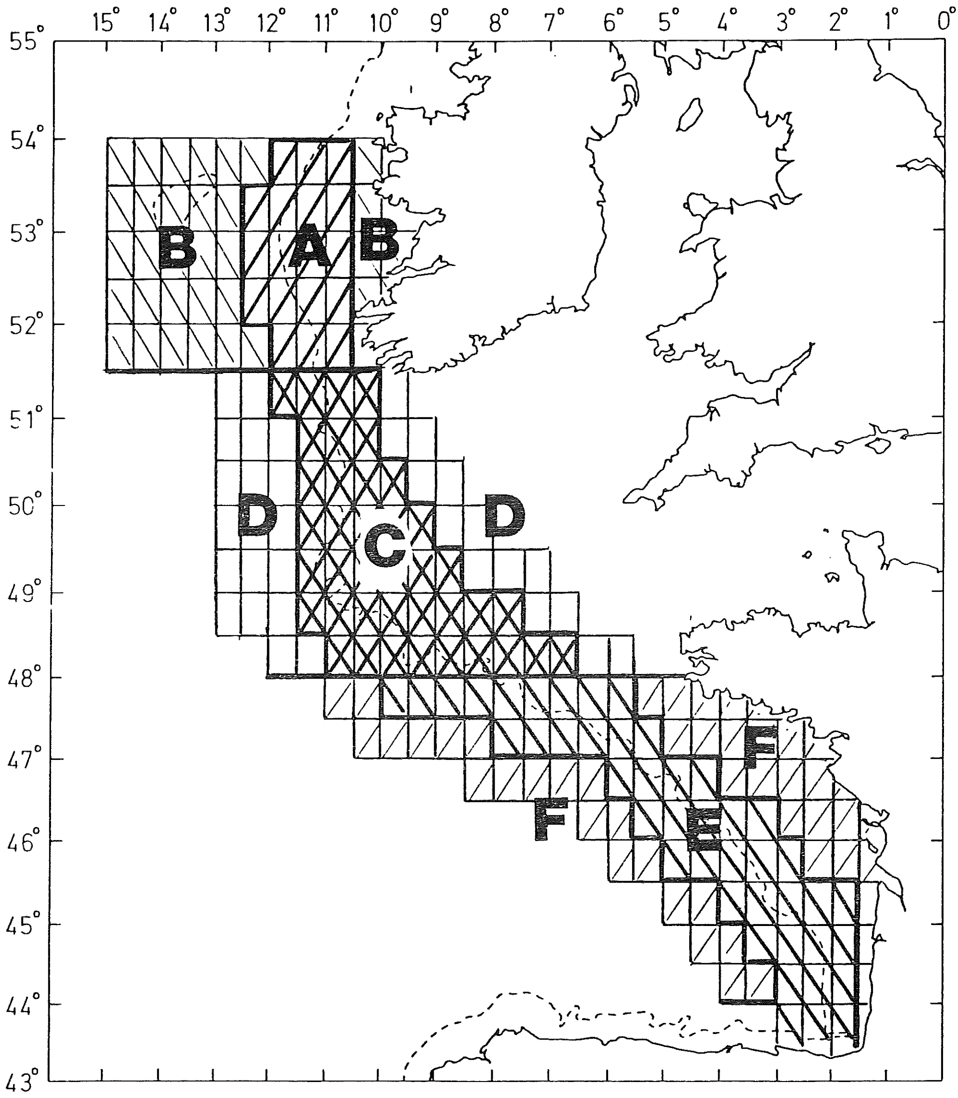
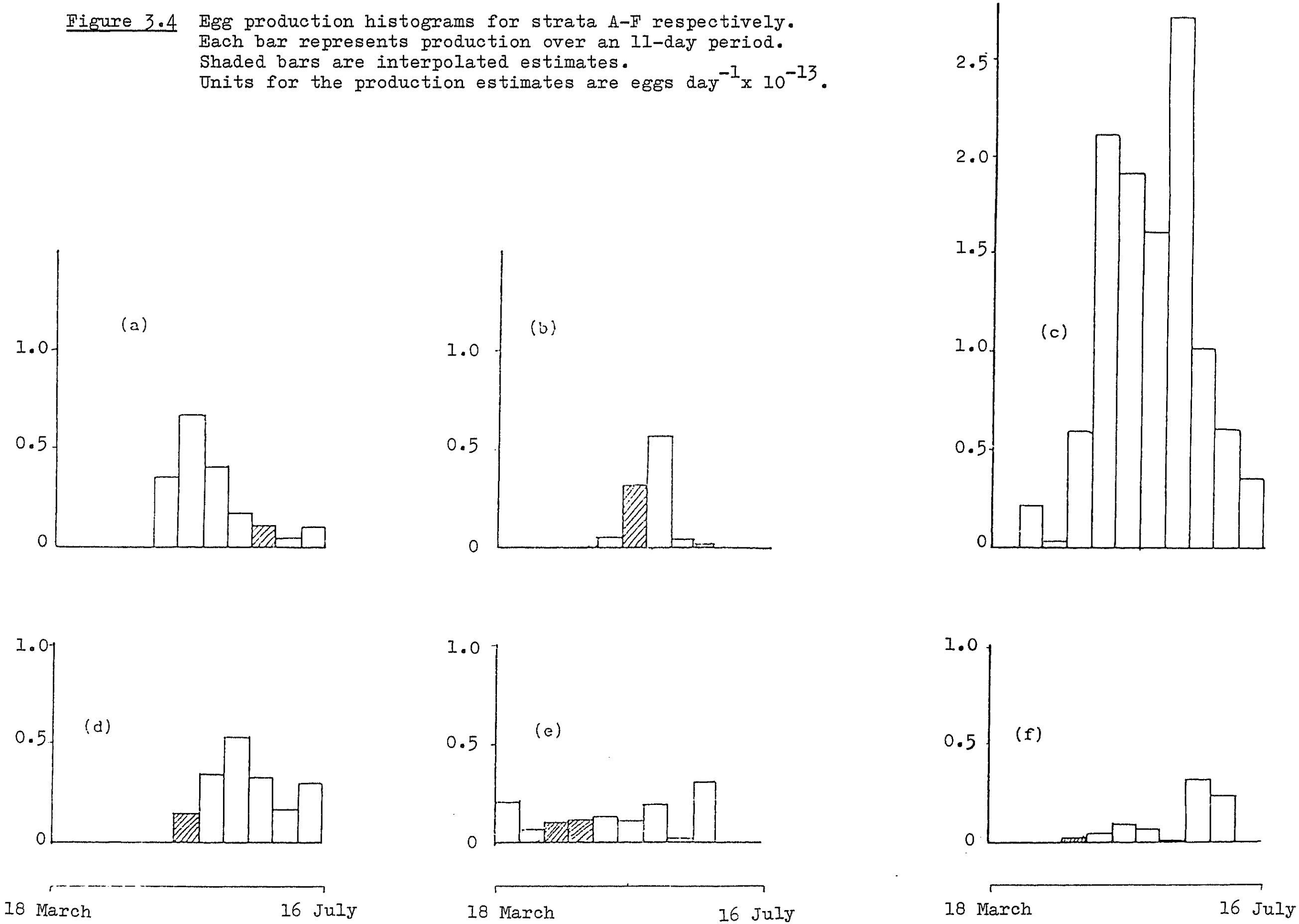


Figure 3.3 Stratification adopted for analysis of Δ-distribution.

Figure 3.4 Egg production histograms for strata A-F respectively. Each bar represents production over an 11-day period. Shaded bars are interpolated estimates. Units for the production estimates are eggs $day^{-1} \times 10^{-13}$.



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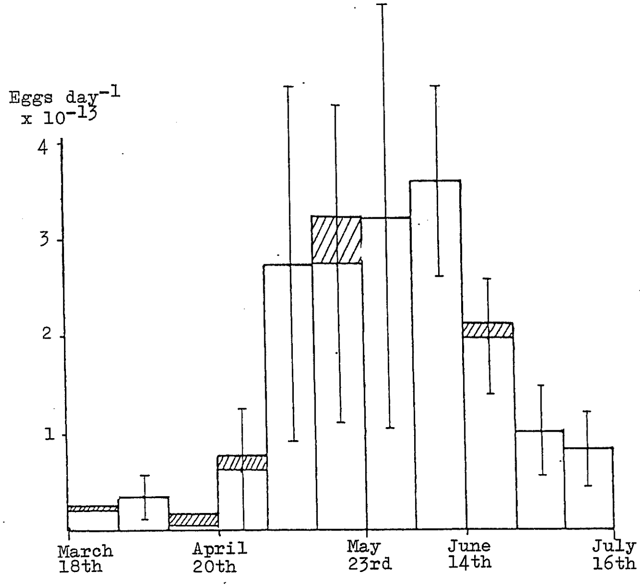
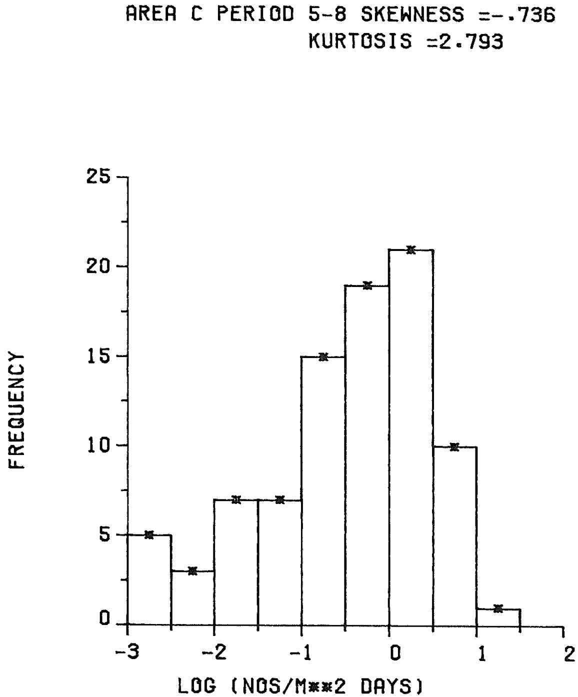


<u>Figure 3.5</u> Egg production histogram for the 1983 Western MACKEREL egg survey. Each bar represents production over an 11-day period, the shaded areas representing the contribution of interpolated values.



<u>Figure 3.6</u> Analysis of egg production data from stratum C (Fig.3.3) for skew and kurtosis.

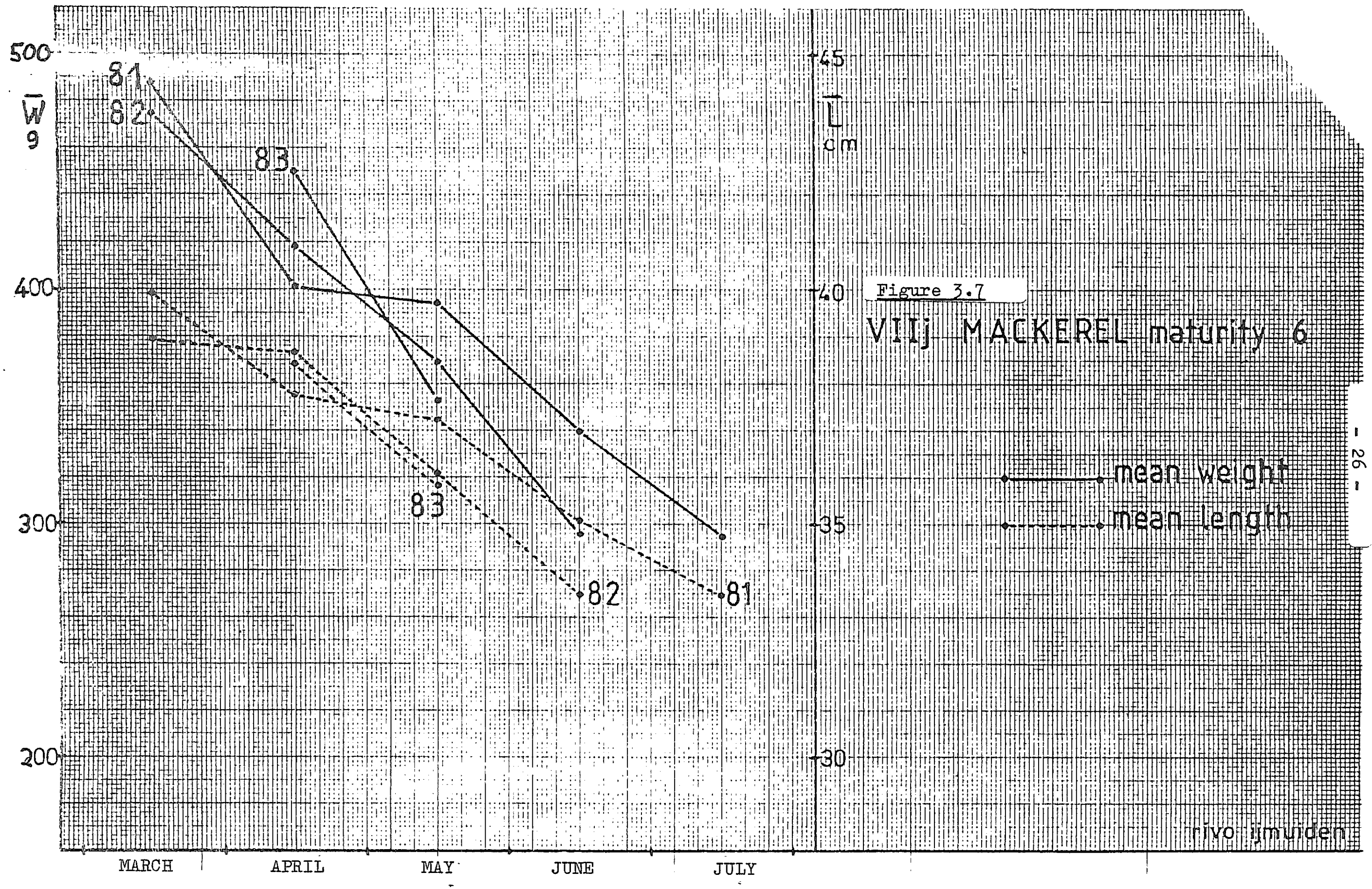


Figure 3.7

VIIj MACKEREL maturity 6

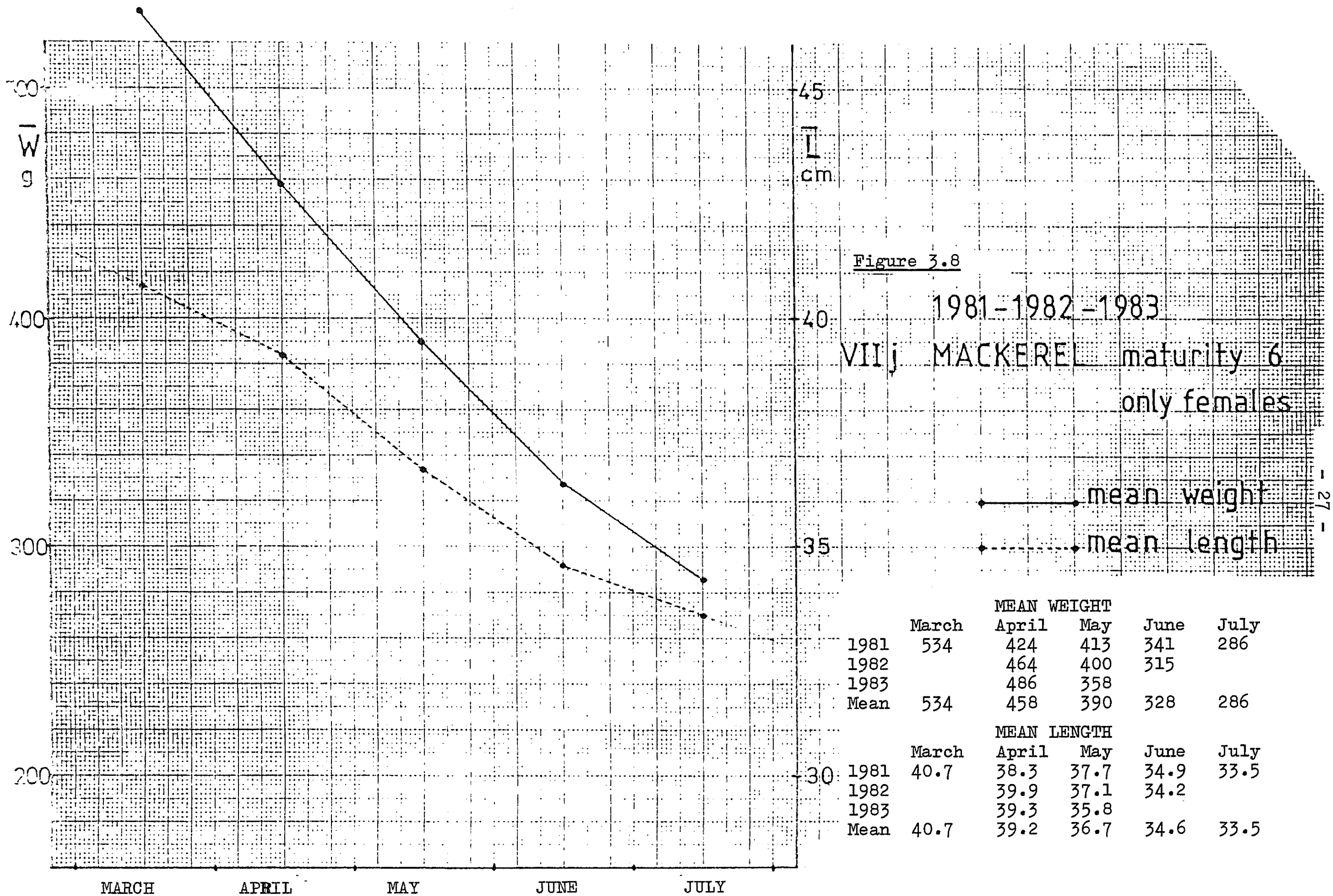


Figure 3.8

1981-1982-1983

VIIj MACKEREL maturity 6

only females

MEAN WEIGHT

	March	April	May	June	July
1981	534	424	413	341	286
1982		464	400	315	
1983		486	358		
Mean	534	458	390	328	286

MEAN LENGTH

	March	April	May	June	July
1981	40.7	38.3	37.7	34.9	33.5
1982		39.9	37.1	34.2	
1983		39.3	35.8		
Mean	40.7	39.2	36.7	34.6	33.5

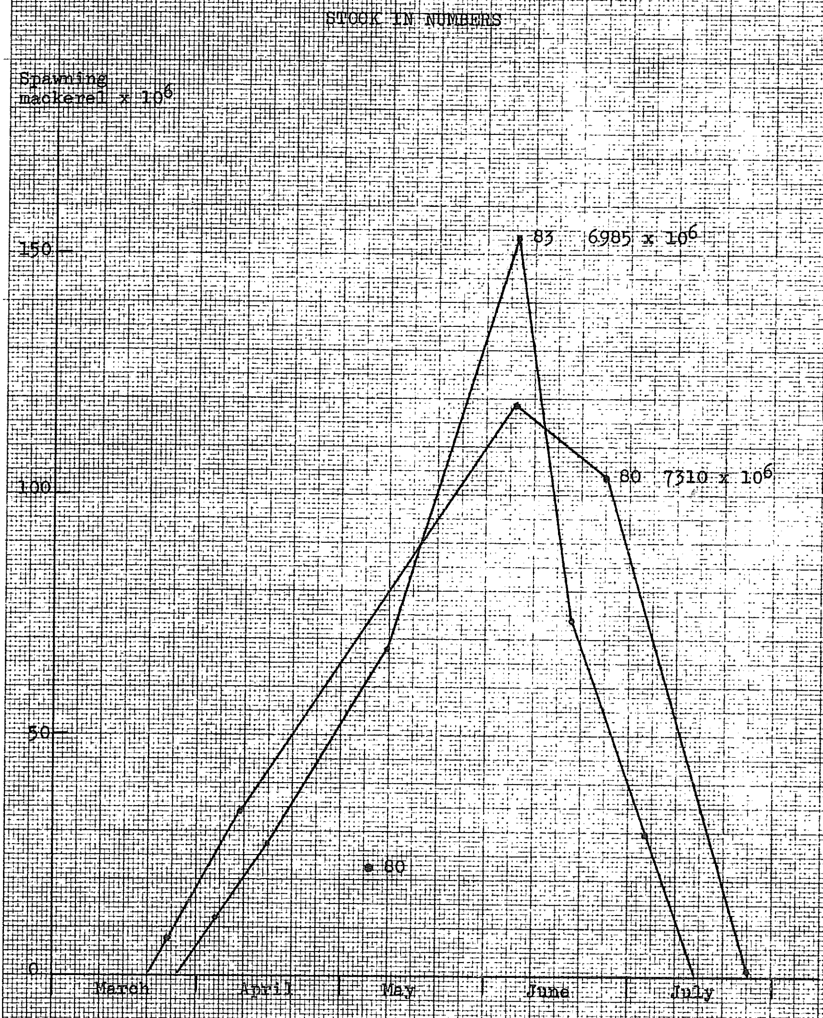


Figure 3.9 Western mackerel spawning stock in number through the spawning season, March to July, during 1980 and 1983. (The estimated stock in number for May 1980 has been omitted. For explanation, see text.)

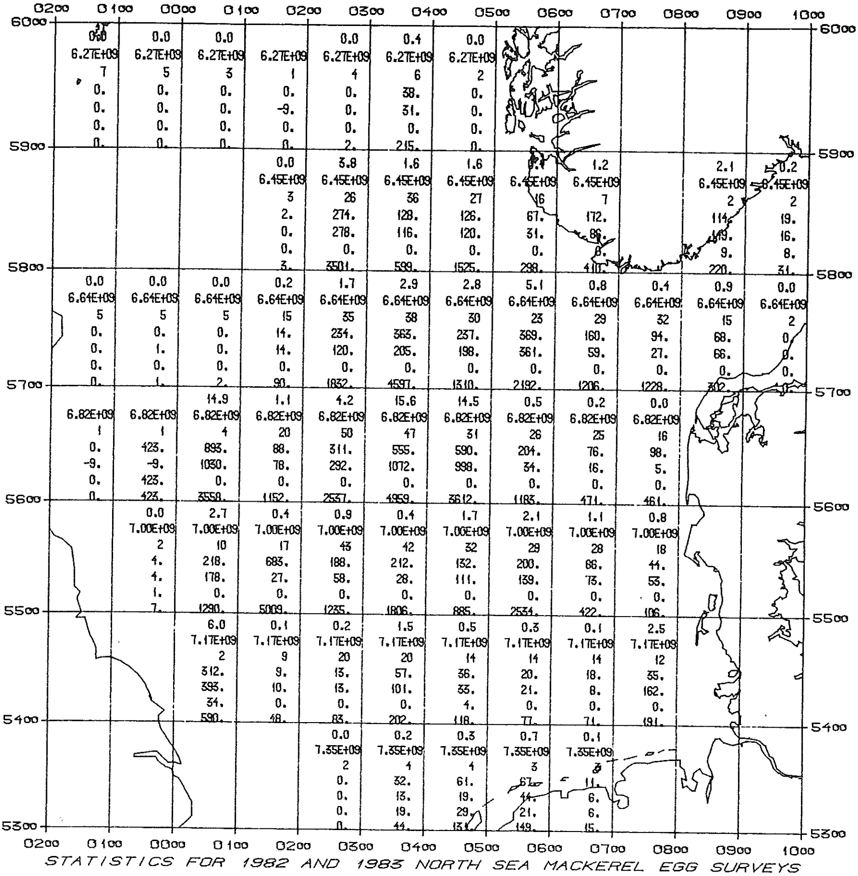


Figure 4.1 Statistics for the 1982 and 1983 egg surveys in 1 x 1 degree rectangles. From top to bottom the figures are: Optimum percent of total effort (Neyman), Area of rectangle in m^2, number of stations, mean number per haul (all stages), standard deviation, minimum value, maximum value.

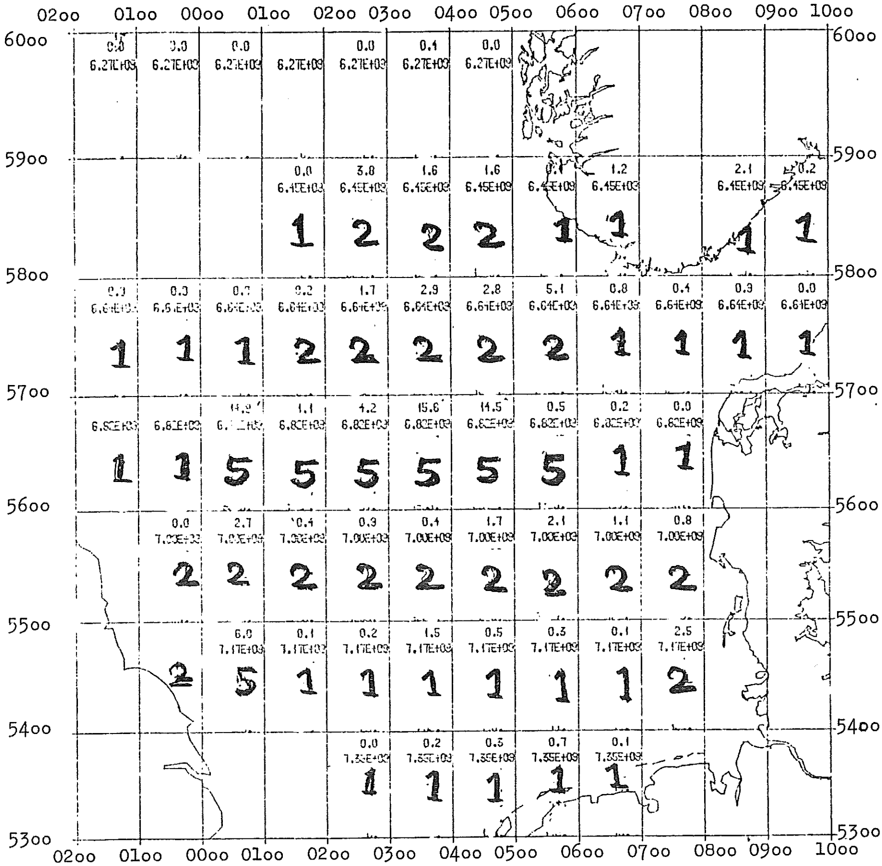
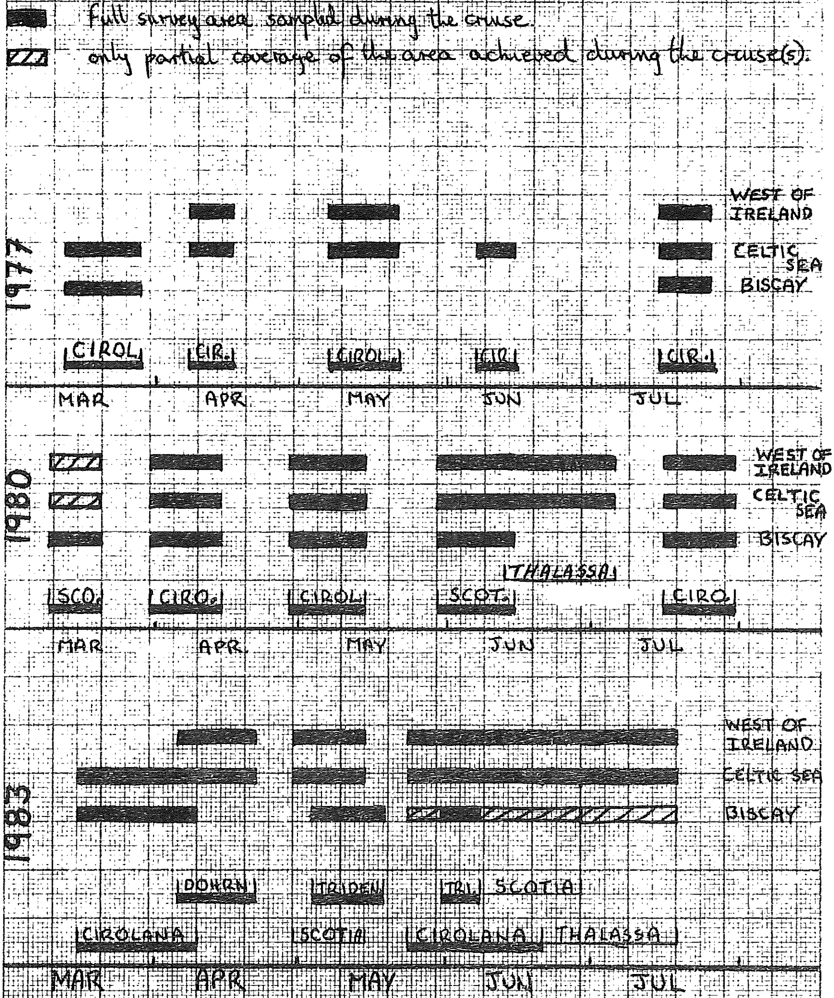


Figure 4.2 Proposed sampling effort for the mackerel egg survey in the North Sea in 1984.

Figure 5.1

Coverage achieved during egg surveys on the continental slope.



Cruises heavily underlined are those from which scad egg data are available